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SUMMARY

A preliminary study has been made to determine a logical next step after Shuttle in our utilization of space. It has resulted in definition of a Manned Orbital Service System (MOSS) concept consisting of a two-man crew module mated with a propulsion module. The resulting spacecraft would remain in low Earth orbit for months or years at a time conducting civil or military satellite servicing, experimental, or applications missions while being periodically supplied and refueled by Shuttle flights from the ground. The system would accumulate experience invaluable to the design of future large and more expensive spacecraft.

Key features of the vehicle are versatility and mobility. With Centaur-type propulsion and a large payload, the MOSS could leave an initial orbit of 370 km (200 nmi) altitude and inclinations up to 56°, make a plane change of up to ±14°, reach altitudes to 5500 km (2970 nmi), and then return the payload to the original orbit altitude and inclination. Obviously, the size of the performance envelope varies with the payload and propulsion unit selected.

The MOSS can reach orbits and perform tasks not possible with Shuttle alone or with the much larger space stations currently being proposed. The small cabin volume and crew size, however, limit the number of tasks that can be conducted simultaneously.

The concept does not require any technology breakthroughs for successful program development, but certain advances in subsystems and operational

techniques are necessary for the system to attain its full operational potential.

INTRODUCTION

Early Space Station History

The Langley Research Center has been in the forefront of research on manned space stations, the generalized term used for spacecraft designed to extend crew staytime in Earth orbit, almost since the idea was conceived.

It seems appropriate, then, to summarize this early history as the starting point for placing the current approaches to space program expansion in proper perspective.

In 1952, a group of visionary scientists and engineers including Dr. Wernher von Braun, Dr. Joseph Kaplan, Dr. Fred Whipple, Dr. Heinz Haber, and Mr. Willey Ley proposed that the United States orbit a large, artificial-gravity manned space station. It was to be accompanied by a system of reusable logistics support vehicles and space taxis and include a zero-gravity module for Earth and space observations. The major objectives of this program were essentially sound, and they have been pursued, albeit sporadically, ever since.

Langley Research Center management recognized the space station potential in 1959 and initiated what may have been the first significant organized research effort in that area. The results of early work in configurations, structures and materials, stabilization and control, and crew-related topics such as life support and human performance were presented in NASA's first Space Station Symposium which was held at LaRC in mid-1962 (ref. 1).

Subsequent to the 1962 symposium, other NASA Centers began extensive, in-depth space station research and development. Langley's efforts expanded to include major in-house and contractual work on systems integration, logistics vehicles, mission simulation, on board experiments, crew performance at reduced gravity levels, and effects of closed environments. The Manned Orbital Research Laboratory (MORL) systems studies, conducted under contract from 1963 to 1966, were managed by LaRC and cost over four million 1965 dollars. They represented the first comprehensive and definitive space station effort.

The Center spent another six million dollars on related supportive areas such as attitude control, life support, and electrical power before the end of 1969. In addition to the usual studies, full-scale hardware was developed and manned simulations conducted.

Meanwhile, several NASA-wide in-house working groups and NASA-sponsored contractors were generating lists of uses for the space station, and designing the implementing equipment and vehicle interfaces. Experiment programs in astronomy, the biological sciences, human tolerance and performance, the physical sciences, and the engineering disciplines were developed. Direct applications in the field of communications, meteorology, and geology were planned.

At the Agency-wide Space Station Technology Symposium hosted by Langley in February 1969 (ref. 2), it was possible to say, therefore, that space station technology was generally in hand for commitment to viable design. Remaining problems could be resolved by incorporating the necessary flexibility or redundancy in the final system.

The optimism of 1969 did not lead to a positive decision for a national space station program; instead, the early 70's saw the effort deemphasized even as the first temporary space station, Skylab, was preparing to fly in 1973.

There were at least three reasons for the failure to obtain a go-ahead at that time.

First was the high cost of expendable resupply vehicles. A study by the Science and Technology Steering Committee, for example, recommended a long duration manned space station, but it gave higher priority to a low-cost reusable space transportation system as the keystone to the future use of the new environment. The nation was apparently not in a position to afford both the station and the logistics system, hence the decision by President Nixon in January 1972 to proceed with the Space Shuttle alone.

Second was the failure by proponents to develop a compelling need for the space station. Emphasis in many of the early studies seemed to be on use of the station as a research laboratory in space, or as an extension of the same kind of laboratory that NASA used for research on the ground. Designation of the MORL as a research lab is an example of this. Exploitation of special properties of the space environment for manufacturing or observational purposes was certainly proposed, as was use of the platform as a stepping stone to further manned exploration of the Moon or planets. These seemed to be of secondary importance, however. Military applications were sometimes recognized, but except for the short-lived Air Force Manned Orbital Laboratory (MOL) program, they were seldom emphasized.

An invulnerable justification still cannot be presented at this time. However, more attention can be given to satellite servicing, military applications, and space construction or manufacturing than has been done in the past.

Third, a permanent large system for the late 70's may have been an idea a little ahead of its time. For instance, by postponing it until the late 80's, there will be a routinely reliable Earth-to-low-Earth orbit and probably a low-Earth-to-geosynchronous orbit transportation system to support it. Also there should be dozens or even hundreds more satellites in various orbits that can benefit from the servicing, modification, or military capabilities of a nearby manned facility.

Again, there is now a significantly improved data base on human durability and capability in the zero-gravity environment, and there are more performance data on operational hardware systems and computers. This will allow station design to be more efficient and approached with added confidence. It was thought several years ago, for example, that any long-duration manned habitat would need to include provisions for artificial gravity for the crew, at best a costly and complicating accessory. Favorable experience on both Russian and American extended duration manned flights indicates that may no longer be a requirement.

Current Approaches

Now that the development phase of the Space Shuttle has been completed, strong interest in a "permanent" manned space station has again surfaced. Several proposals have been advanced as the next logical step after Shuttle for expanding operations in near-Earth orbit.

One of these proposals is the Space Operations Center (SOC), presented in reference 3. It is a large, Shuttle-serviced, long-duration facility maintained in low-Earth orbit. Assembled from components that are Shuttle launched, it would have a crew of four to eight people and a resupply interval of up to 90 days. Its objectives are servicing of nearby satellites and platforms, staging for high energy missions, assembly and construction of large structures and, with the aid of a separate reusable orbit transfer vehicle, servicing of spacecraft in higher energy orbits.

A somewhat similar system is the Science and Applications Manned Space Platform (SAMSP), described in reference 4. It is essentially a large experiment platform with a Spacelab-derived habitability module for a crew of four. The spacecraft components would be Shuttle-launched and then assembled in low-Earth orbit. It could be continuously manned and resupplied every 90 days. Planned activities include experiments in solar physics, space plasma physics, astronomy, astrophysics, and the life sciences; Earth resources and environmental observations; and materials processing.

Other methods being considered to enhance our utilization of space include modifications to Shuttle to augment its current capability. Main engine thrust uprating, spacecraft weight reduction, and development of upper stages can open up the performance envelope. Autonomous guidance, navigation, and control and improved fuel cells or addition of solar panels could increase Orbiter mission length from the current design value of 28 man-days to 140 man-days. Addition of tethered satellites for enhanced experiment capability, redesign of the payload bay or addition of an aft cargo compartment to increase payload volume, and employment of new remotely controlled satellite servicing devices each have the potential to improve the versatility of Shuttle.

All of these systems could no doubt lead to increased permanency of man in space and give him more freedom to exploit the space environment. What may be more relevant at this time, however, is a reexamination of the role most likely to be played by the next generation of manned spacecraft so that more specific performance characteristics may be defined and a more responsive concept developed.

The purpose of this paper, therefore, is to briefly examine predicted activity in near-Earth space for the next decade or 2, assess to the ability of currently proposed spacecraft systems to support the scenario, and present an alternate concept for consideration.

ALTERNATE CONCEPT RATIONALE

The Missions

The current administration's highest priority goals for the United States are improvement of the domestic economy and national security. However, economic benefits from a space station may not be realized for several years after initial operation, and therefore are not suitable as a near-term justification. Rather, national security in the broadest sense offers a strong and unifying theme for a space station for the 1990's.

Both government and private sector investments in space hardware are substantial. The federal investment in satellite systems, both civil and military, is well-known. Also, an important fraction of the non-government business for a number of large U.S. corporations is based on free access to space by foreign and our own business interests.

The United States and Russia are now the principal users of space, the U.S. having 398 satellites in Earth orbit as of December 31, 1980, and the USSR 471 (ref. 5). This activity is expected to increase rapidly over the next 20 years, and indeed expand to include the countries of France, Japan, Great Britain, and West Germany. A typical projection of additional satellite traffic to low Earth orbit by this country alone between 1982 and the year 2000 is shown in figure 1.

Obviously, there will continue to be hundreds of spacecraft in near-Earth space in the next couple of decades. Our national security is thus served by having the ability to move people and machines to pertinent locations there for the purpose of supporting commerce and for the protection of our national interests in this new environment.

The operating regime of concern covers altitudes from 280 km (150 nmi) to 36,000 km (19,400 nmi) and orbit inclinations from 0° to 100°. The kinds of tasks that must be performed within this operational envelope are presented in figure 2.

Included are the servicing of civil and military satellites in various orbits, the launch and retrieval of satellites in low energy orbits, and assistance with staging required for injection into high energy orbits. Testing of advanced space hardware, weapons, and operational techniques must be conducted, as well as support of science and applications experiments and development of space construction and materials processing methods.

Direct military functions include use of a manned satellite as a command post, weapons platform, or sensor platform. The advantages of space for military activities are receiving increasing attention in current national defense and budgetary planning.

The Generic Spacecraft

A system best suited to perform the kinds of missions just described should first of all be manned. The strongest justification for the spacecraft is probably its use in servicing accessible satellites. Here, a crew makes possible a higher level of diagnostic ability and contingency or emergency performance than can be realized with automated equipment alone. Similarly, a crew can enhance the success of particularly sensitive military missions.

The vehicle must be mobile and have the ability to routinely change altitude and orbit inclination within the performance envelope of interest.

Compatibility with Shuttle both in the launch phase and in the resupply or turnaround mode is required. The frequency of Shuttle flights should be minimized, however, to reduce costs.

The vehicle should be small enough (and thus light enough) to allow good orbital performance with a modest propulsion system, and yet have a pressurized cabin of sufficient size for long-term occupancy and a versatile work space.

At least the manned module portion of the spacecraft must be capable of remaining on orbit for several years with resupply intervals of 30 to 90 days if continuously occupied. The propulsion system may have to be returned to Earth periodically for main engine overhaul.

Of course, system hardware and operational costs must be kept low. The best ways to do this are to keep the vehicle small, make it versatile so that one spacecraft design can accomplish several tasks, and reduce Shuttle resupply flights by extending crew staytimes or utilizing new fuel-saving orbital transfer techniques.

Unfortunately, the currently proposed post-Shuttle concepts described in a previous section of this paper have significant limitations when compared to the characteristics just outlined.

Shuttle itself is not well equipped to operate freely among various orbits as a pure spacecraft. It is heavy (74,830 kg or 165,000 lb empty) and has a limited orbital lifetime. It is also not designed for close contact with other space objects or as a space tug. In spite of planned performance upgrading and capability enhancement programs, the Orbiter must always remain too large and too awkward for efficient orbital maneuvering because it is encumbered with the wings, tail surfaces, thermal protection system, and landing gear required for reentry and touchdown.

The primary disadvantages of the large concepts such as SOC and SAMSP are cost and lack of mobility. They are generally confined to the orbits into which they have been initially injected. In order for them to service satellites in other orbits, a small additional auxiliary or support spacecraft (orbit transfer vehicle) would be required to extend their effective operational range. The resulting system would be very expensive and relatively complex. Some operations would also be very time consuming and excessive users of propellants since a target spacecraft would have to be towed to the repair depot (SOC) and subsequently returned to its original orbit.

Summed up, these limitations seem to indicate that a new spacecraft design is needed that is more responsive to the stated requirements.

SYSTEM DESCRIPTION

MOSS Concept

In response to our national needs and based upon the desirable systems characteristics previously described, an alternate spacecraft concept tentatively named the Manned Orbital Service System (MOSS) has been derived.

As indicated in figure 3, MOSS consists of a standard manned service or crew module attached to an appropriate propulsion module that would be sized to suit the class of mission to be addressed. For initial deployment, one Shuttle flight each is used to carry the crew and propulsion modules separately to an altitude of 370 km (200 nmi) at orbit inclinations up to 56°. Once on orbit, the modules are mated with assistance of the Shuttle Orbiter to become an operational, autonomous spacecraft.

The spacecraft would stay on orbit for several years, performing various missions in different orbits as required. It would be resupplied periodically by Shuttle flights to furnish fresh crews, life support consumables, various fuels and propellants, and specialized mission equipment.

Turnaround maintenance between major sorties would be accomplished on orbit assisted by Shuttle initially and perhaps by a SOC-type spacecraft later on in the program. The main engines in the propulsion module may require a major ground overhaul about every eight sorties, but the crew module could be decoupled and retained on orbit for use with a replacement propulsion unit.

Physical Characteristics

Pertinent physical parameters of MOSS have been estimated in order to define some first order Shuttle compatibility, mission potential, and performance characteristics. The data are based in part on information presented in references 6, 7, and 8 that have been modified to suit the present configuration.

The crew module is a pressure vessel with a diameter of 3 m (9.8 ft) and a length of 4.35 m (14.3 ft). It has been sized to provide relative comfort for a crew of two for at least a 30-day mission. With two people, the cabin free volume is about 4.75 cu m per man. As can be seen in figure 4, this is significantly better than the Celantano performance curve for volume required as a function of mission length. Based on these data, the module is probably large enough for missions considerably longer than 30 days. Of additional significance is the sufficiency of free space to conduct experiments or bench repair tasks.

In order to retain viability during absence or shutdown of the propulsion module, the crew module should have its own electrical power, thermal control, avionics, life support, and attitude control systems. Actual division of subsystems between the propulsion and crew modules and whether they should be located on the inside or outside of the pressure shell will require further detailed study.

The cabin atmosphere is two gas (oxygen and nitrogen) at a total pressure of 55 KPa (8 psi). A 5-KW fuel cell electric power system is provided for the shorter missions. For sorties longer than 15 days, the fuel cells are augmented by a solar array.

The system would have EVA capability as well as internally controlled external manipulators. The airlock function could be performed by pumpdown of the crew module cabin or by an expandable low-volume airlock such as that described in reference 9. Design lifetime of the system would be about 30 sorties (of the 30-day type) or a total of 10 years. Turnaround maintenance between sorties would be accomplished on-orbit.

A preliminary weight estimate of the MOSS crew module indicates 7785 kg (17,165 lb) in a mission-ready condition for a 30-day sortie. Details of the estimate are shown in table I. Fixed component weights include a 20-percent contingency, and consumables include provisions for an extra 2 days mission length. Actually, the estimate is for a rather complex, lengthy mission. Simpler and shorter service sorties could be accomplished at weights up to 1360 kg (3000 lb) lower than that shown.

Hopefully a design compromise has been attained wherein the crew module is large enough to house two people comfortably with enough free space to do some work, and yet small enough to be compatible with Shuttle payload bay limitations and have a reasonable orbital performance envelope with planned or existing orbital transfer stages.

Two propulsion modules with different thrust capabilities were considered for the MOSS system. The larger is based upon Centaur technology and has been coded as OTVX for this study. It has a maximum diameter of 4 m (13.1 ft) and a length including a standardized crew module attachment ring of 9.15 m (30 ft). The engine has an I_{SP} of 461 seconds, and the module was designed with a mass fraction of 0.9. Total fueled weight of the module is 18,594 kg (41,000 lb), currently the maximum payload the Shuttle can lift to a 370 km (200 nmi), 56° inclination orbit.

A smaller propulsion module considered for MOSS is a slightly modified Titan transtage. It has a diameter of 3.05 m (10 ft) and is 4.63 m (15.2 ft) long including a crew module attachment fitting. Its engine has an I_{SP} of 305 seconds, and it weighs 12,390 kg (27,320 lb) in the fueled, flight-ready condition.

Both propulsion stages are designed for long life on-orbit, and for on-orbit maintenance and refueling. However, the main engines may require major ground overhaul about every eight full-length sorties.

The length, diameter, and total weight of the crew module, propulsion modules, and the assembled MOSS spacecraft are shown on figure 5. The same figure indicates current net Shuttle payload limitations to the 370 km (200 nmi, 56° orbit and thus provides an opportunity to assess compatibility of MOSS spacecraft, even the OTVX-powered version. The assembled weight of the OTVX MOSS, however, is 26,739 kg (58,165 lb), well in excess of Shuttle capability to the desired orbit. Obviously for the flight conditions and MOSS configuration assumed here, the crew and propulsion modules will have to be carried into orbit with the OTVX only partially fueled for its first mission.

The transtage-powered concept at 20,175 kg (44,486 lb) is also somewhat heavy for Shuttle at the desired orbit. However, it could be placed in an orbit of slightly lower energy by one Shuttle flight fully fueled. Finally, weight compatibility comparisons are expected to be altered favorably as Shuttle performance upgrading process.

PERFORMANCE CHARACTERISTICS

Since the primary objective of MOSS is to move about in various orbits to service other satellites, the magnitude of its orbital altitude and plane change envelope using one full load of propellant is taken as the measure of its performance.

These envelopes have been calculated for MOSS with the OTVX and transtage propulsion modules and are presented in figures 6(a) to 6(c) for payload weights of 4540 kg (10,000 lb), 7710 kg (17,000 lb), and 9100 kg (20,000 lb), respectively. The payload is the mission-ready crew module and its weight has been assumed constant for the complete sortie. Two cases have been calculated for each sortie. In the first, the payload is returned to the initial orbit inclination at the initial altitude of 370 km (200 nmi). In the second, the payload remains in the new orbital plane, but returns to the initial altitude.

Of most interest is the 7710 kg (17,000 lb) payload (fig. 6 (b)), since it represents the design crew module. As indicated, the OTVX-propelled spacecraft is capable of plane changes of up to ±14° and altitudes up to 5500 km (2970 nmi) if the payload must be returned to the initial orbit. With injection of 56°, orbit coverage from 42° to 70° inclination is possible. This includes those orbits and views of those portions of the Earth's surface of most value for national security purposes. If the payload need only be returned to the initial altitude, but can remain at the new inclination, the orbit transfer requires less energy, and plane changes as high as ±28° are possible.

For the smaller transtage concept, orbital changes are reduced to a maximum of ±7° inclination and 2400 km (13,000 nmi) altitude for payload return to the initial orbit. Inclination changes to ±14° are possible if return is only required to initial altitude.

A crossplot of the major performance parameters as a function of payload weight is shown in figure 7. Altitude and plane change capability obviously varies inversely, the sensitivity increasing as the payload becomes a smaller portion of the total spacecraft weight. At any rate, it is apparent that the operating envelope for MOSS is quite large with OTVX propulsion.

APPLICATIONS

In order to gain a realistic impression of the usefulness of the MOSS concept, a survey was made of satellites launched beginning January 1975 and still operational in December 1980 to determine how many can be rendezvoused with (in circular orbits) or those additional satellites which could be intercepted (in elliptical orbits) by the OTVX or transtage propelled MOSS spacecraft. After rendezvous or intercept it was assumed that the MOSS would return to its initial orbit.

OTVX coverage was assumed to include inclinations from 14° to 70° and altitudes from 100 up to 5500 km (54 to 2970 nmi) depending upon the plane change required. Shuttle launches of MOSS from ETR to inclinations fo 28° and 56° at 370 km (200 nmi) altitude would be necessary to cover this range. The transtage includes inclinations from 21° to 63° at altitudes up to 2400 km (1300 nmi) using initial orbits of 28° and 56° inclination.

The results of the survey (fig. 8) show that a total of 51 satellites could be serviced by OTVX in the rendezvous mode and 66 more using interception. With the transtage propulsion module, rendezvous with 18 satellites can be accomplished and interception of eight more is possible.

Further analysis indicates a WTR launch to a 370 km (200 nmi) altitude would allow coverage to an inclination of 80° and up to 1600 km (864 nmi) altitude. This would pick up an additional 155 USSR satellites included in the survey.

When this large number of MOSS-reachable satellites already in orbit is supplemented by the predicted additional heavy traffic to low Earth orbit betwen now and the year 2000, it becomes apparent there will be hundreds of candidates for in-space launch, servicing, and retrieval. With its mobility and large operations envelope, MOSS will also be able to conduct many different experimental and direct applications missions, both military and civilian.

Representative applications of MOSS can be illustrated by the 1-year mission model presented in figure 9. The model begins with orbit injection of the crew module and partially fueled propulsion module that make up the operational spacecraft. The first sortie is a minor one consistent with a partially fueled OTVX and a checkout mission. Note that these and the following flights are numbered consecutively, even though the same vehicle might be used several times per year. The direction of the flights (up or down) is indicated by arrows.

Several minor sorties for satellite servicing or experimental work are then performed in orbits relatively near to the injection orbit. After experience has been gained, two major sorties are undertaken that involve much larger orbit transfers. The crews for these missions are again numbered consecutively for clarity. Actually, the same people might be utilized two or three times each year.

Typical mission length is about 30 days, with a 3-week on-orbit turnaround for maintenance and refueling required after a major use of the propulsion unit and only 1 week after a minor sortie. Crew rotation times vary from 42 to 49 days, and the minimum number of Shuttle flights required is 13 per year. Emergency or contingency flights would be additional, and later on in the program the propulsion module would require ground turnaround maintenance and thus one extra flight.

Early MOSS missions would probably involve tasks such as inspection, instrument replacement, cleaning optical surfaces, making simple repairs, and unjamming mechanisms on cooperating satellites. Later, increasingly sophisticated servicing would include uncooperative spacecraft, component replacement, upgrading, or launch of high energy stages. Related activities would include attendance at multicomponent unmanned space platforms, science and applications experiments, and support of R&D on space construction, materials processing, and military weapons systems.

Special tools and mechanisms to assist in implementing these tasks are already being developed and could be available for timely use on the MOSS spacecraft. They include a master/slave manipulator system, workpiece stabilizer, and open cherry picker work platform (ref. 7); a handling and positioning aid, remote manipulator system, and payload installation and deployment aid (ref. 10); and maneuverable television, proximity operations module, and manned maneuvering unit (ref. 11). A noncontaminating cold-gas propulsion system has also been proposed for maneuvering MOSS near contaminant-sensitive satellites.

EXPANDED CAPABILITY

It is possible to enhance the capability of MOSS to perform certain missions by making additions or modifications to the original configuration.

These changes are not without cost, however, and usually result in decreased versatility or mobility.

Figure 10 illustrates addition of an extra crew module to the basic spacecraft. The module might be a laboratory for conducting experiments, living quarters for additional crew members or extending orbit staytime, a pilot plant for space materials processing, or a platform dedicated to military objectives. Free volume of the spacecraft would be doubled, but the increased weight would reduce the size of the orbit altitude/plane change envelope. As illustrated in reference 9, the cabin volume could be increased even more by using expandable structures concepts. These are relatively lightweight, and when packaged are small enough to be brought into orbit on the same Shuttle flight as the crew module.

Another concept utilizes the empty Shuttle External Tank (ET) to gravity-stabilize the MOSS in an Earth-pointing mode, thus minimizing expenditure of RCS propellant shown in figure 11.

Figure 12 shows use of the MOSS-ET combination as the core hardware for a larger and longer duration space station or platform. These vehicles would have similar advantages and disadvantages to the SOC and SAMSP concepts previously described.

Augmentation of the propellant supply to allow payload delivery to geosynchronous or other high energy orbits can be accomplished in several ways. Utilization of the fuel remaining in the Shuttle ET after its mission is completed has been proposed. Additional propellant tanks could be fitted to the MOSS spacecraft in a manner similar to that for the Grumman manned orbital transfer vehicle discussed in reference 7 and shown in figure 13. Such a spacecraft, however, requires several Shuttle flights for injection and assembly of components and an estimated 6-week turnaround time between missions.

A method of expanding the MOSS performance envelope for a given fuel supply would be to reduce propellant consumption. One way being studied is to employ aerobraking to deenergize orbits. Another is to use differential modal regression techniques for minimum-energy transfer between satellites having differing altitudes, and which are in different planes with the same inclination (ref. 6).

PROGRAM DEVELOPMENT AND COSTS

Technology Needs

The technology required to successfully develop a long-term space habitat has generally been available since the early 1970's. Since then we have had the additional experience of Skylab and Shuttle and will soon have Spacelab flying as well. The MOSS spacecraft, however, has some functions that are more demanding than previous space station concepts. Many of its subsystems will require technology advances beyond those previously considered. No technological break throughs are necessary, but neither will current off-the-shelf hardware always suffice.

A significant point concerning subsystems and operational techniques for long durations, resuppliable space vehicles, especially those that are manned, is that the initial equipment need not necessarily be functionally and structurally optimum. Availability of Shuttle allows continuing access to new technology being developed on the ground and provides for on-orbit subsystem evolution and flexibility not attainable under former "one-shot" conditions.

A preliminary examination of the MOSS concept suggests that its most critical components are the propulsion system, stability and control system, life support system, and electrical power system. The first two are crucial in terms of being able to return the crew to the Shuttle from orbits which Shuttle cannot reach. The life support system must keep the crew alive and well for extended periods, and electric power is critical to successful operation of the other systems. In addition to functional adequacy all systems must be as light as possible to maximize MOSS mobility.

Some particular areas where focused research and development could result in significant advances include determination of aerodynamic coefficients (especially drag) of complex shapes and prediction of effects of external contamination, plume impingement, and leakage. New tradeoffs of open cycle versus regenerative environmental control/life support systems would be helpful in determining the best components for various classes of MOSS missions. Adaptive control laws for stability and control of masses and inertias that vary during the progress of a mission are required. The weight of power generation, distribution, and storage systems needs to be reduced. Cryogenic fuel storage and transfer on-orbit and development of methods to recover residual fuel from the Shuttle ET would add to MOSS capability. Improvements in the whole fields of automation, fault tolerant computers, dynamics of large flexible structures, teleoperators, and robotics would enhance mission performance and reduce dependency on Shuttle flight schedules.

The ability of MOSS to service other satellites could be augmented by improvement of MOSS hardware and operational procedures. However, the target spacecraft should be designed with easily replaceable components, easily reachable fluid reservoirs, and plug-in diagnostic capability in order to simplify maintenance and repair.

Costs

Although it was beyond the primary scope of this study, some preliminary estimates have been made of the costs of MOSS hardware and on-orbit operations. They are based on data generated for somewhat similar vehicles by Grumman and Rockwell International (ref. 8, 10, and 12). They may be of some value in making rough comparisons with the projected costs of other proposed space station concepts.

DDT&E and Production for the MOSS Spacecraft

Crew module	$ 480 M
Complete vehicle*	$1260 M

On-Orbit Operations for 1-Year MOSS Mission Model

Orbit Operations	$ 75 M
Mission Equipment	$ 5 M
Shuttle Flights	
13 at 28.5 M	$ 370 M
Total	$ 450 M

*For two sets plus spares

If it can be assumed that three satellites could be serviced in low Earth orbit for each of the nine 30-day MOSS sorties, the service cost per satellite is about 16.6 M. By way of comparison, another study estimated low Earth orbit satellite service to cost 7.4 M each if operations were based at SOC, and 24.7 M if conducted by ground-based Shuttle.

A study of servicing satellites in geosynchronous orbit indicated a cost of 35 M each if four were addressed on one sortie. Of the total sortie cost of $140 M, $125 M was for Shuttle flights. These examples show that service costs are dominated by costs of supporting Shuttle flights. These flights must be reduced by basing as much hardware as possible permanently in orbit and extending MOSS resupply intervals as much as feasible.

It might be noted that repairing or refurbishing a damaged satellite is an economical alternative under any of these circumstances. A new communications satellite delivered to low Earth orbit has been estimated to cost about 220 M.

CONCLUSIONS

The Manned Orbital Service System appears to be a relatively low cost, sensible next step after Shuttle in the continuing expansion of our interests and activities in the space environment.

Its greatest assets are mobility and versatility, which led to low cost since several different vehicles are not necessary for a wide variety of missions. Its mobility, especially, gives it a high potential for numerous military applications in orbits of considerable interest.

A limiting factor for a given vehicle and mission is the small cabin volume and crew size. These may be augmented by adding modules, but only at the expense of spacecraft performance.

No technology breakthroughs are required before development could begin. However, many new subsystems and operational techniques must be brought to flight-ready maturity to realize full mission performance and reliability.

This preliminary study has indicated feasibility of the MOSS concept. Nevertheless, in-depth analyses are needed and operational costs are of principal concern, the more nebulous areas needing study in greater detail before a program development plan can be generated or reasonable cost estimates made to include Shuttle cargo bay compatibility, operational interfaces with both Shuttle and the satellites being serviced, subsystems selection (especially electric power) and allocation of subsystems between the crew and propulsion modules, selection of the stable of propulsion systems for the various orbital regimes, and on-orbit and ground-based turnaround maintenance.

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11. Grumman Aerospace Corporation Staff: Executive Summary, Satellite Services System Analysis Study. GAC, July 1981.

12. Grumman Aerospace Corporation Staff: Space Operations Center System Analysis Study Extension. GAC report SA-SOC-RP002, January 1982.

Table I.-Crew Module Weight Estimate

Dry Weight	Kg	(lb)
Structure	1515	(3341)
Thermal Protection	48	(106)
EPS	768	(1693)
Avionics	155	(342)
ECLS	321	(708)
Crew accommodations	610	(1345)
Propulsion control	6	(13)
Contingency (20%)	685	(1510)
Subtotal	4108	(9058)
Crew (2)	163	(359)
Crew consumables	339	(747)
Fuel cell reactants	514	(1134)
Subtotal	1016	(2240)
Mission Equipment		
General Purpose	2269	(5003)
Specialized	392	(864)
Subtotal	2661	(5867)
Total crew module	7785	(17165)

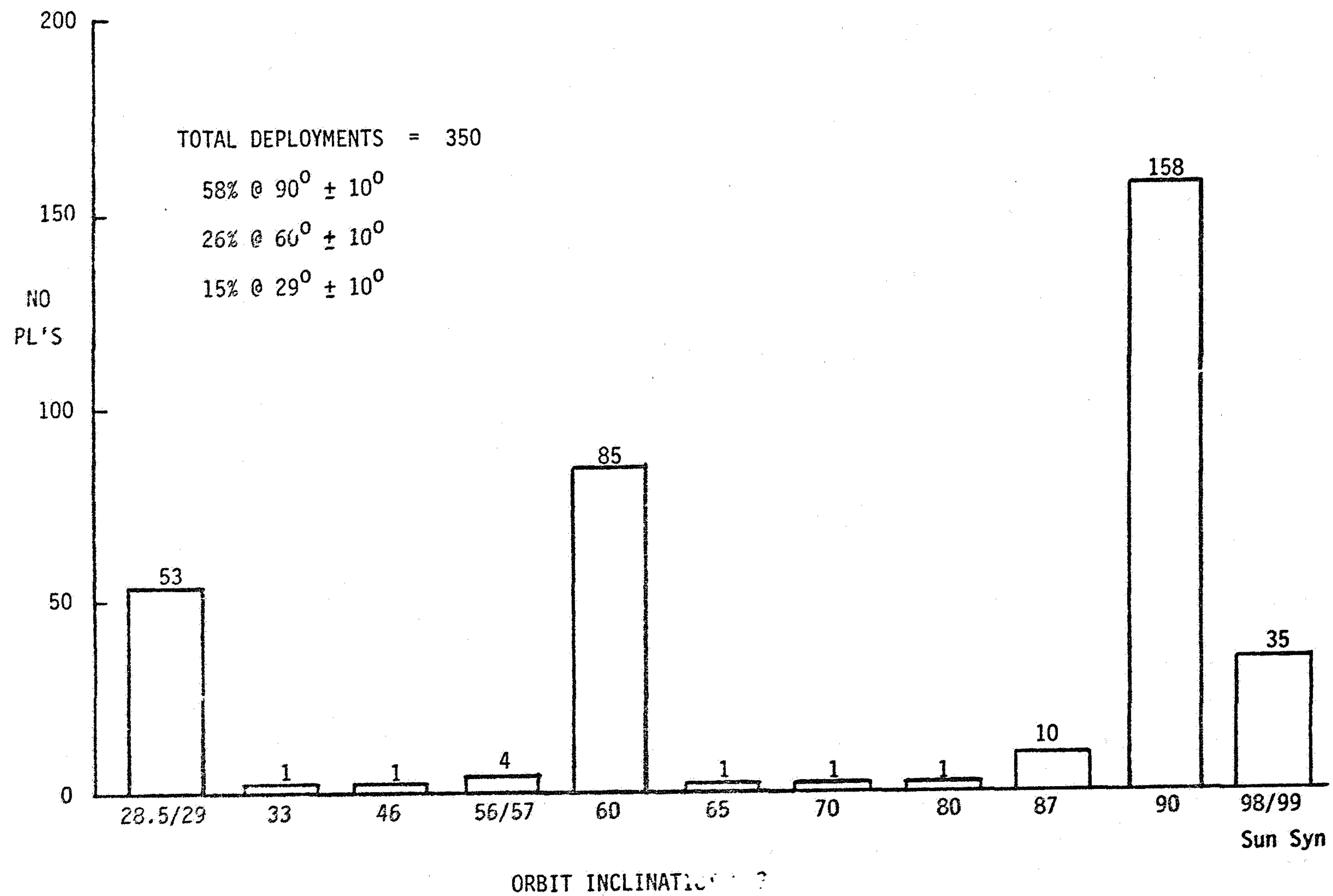


Figure 1. -Projection of U.S. satellite launches to low Earth orbit from 1982 to 2000.

CIVIL	MILITARY
SATELLITE SERVICING ⟶	
SATELLITE LAUNCH AND RETRIEVAL ⟶	
HARDWARE R&D, TESTING	WEAPONS R&D
ELEMENTARY CONSTRUCTION	SATELLITE DEFENSE
SCIENCE EXPERIMENTS	COMMAND POST/C^2
APPLICATIONS DEVELOPMENT	WEAPONS PLATFORM
	SURVEILLANCE/RECON

Figure 2. Tasks to be performed by a manned spacecraft in low-Earth orbit.

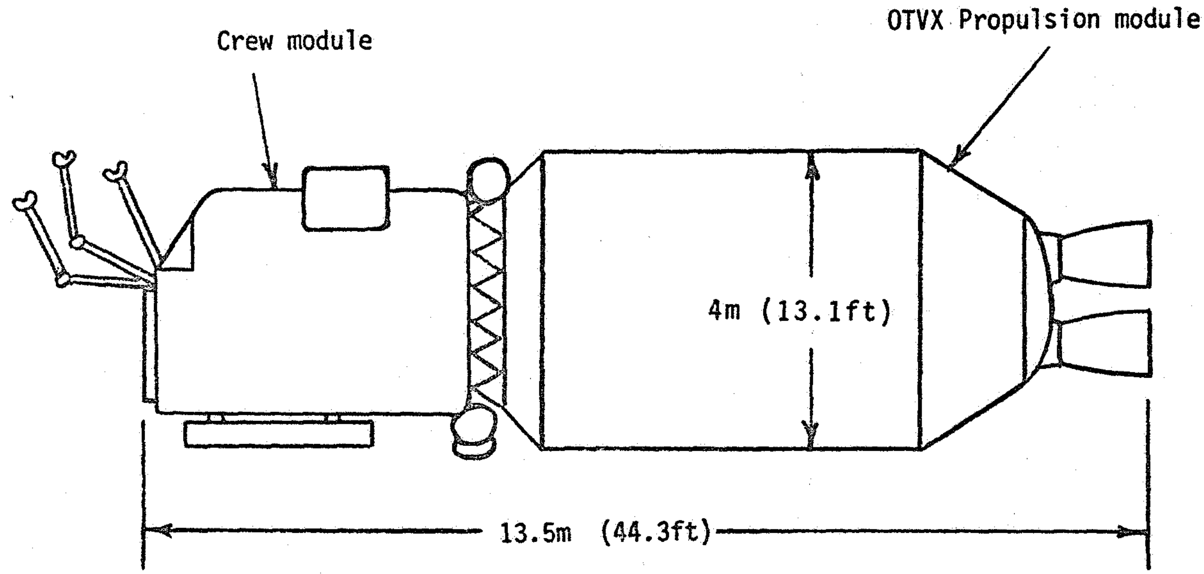


Figure 3. - The MOSS spacecraft with OTVX propulsion module.

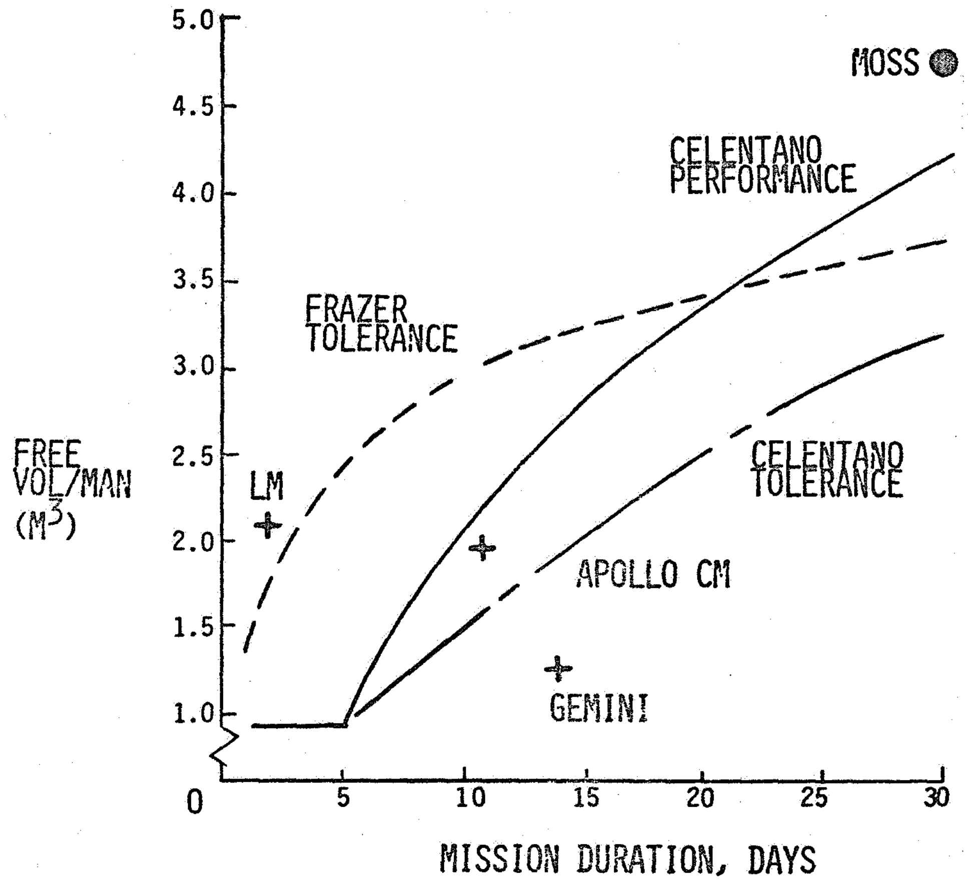
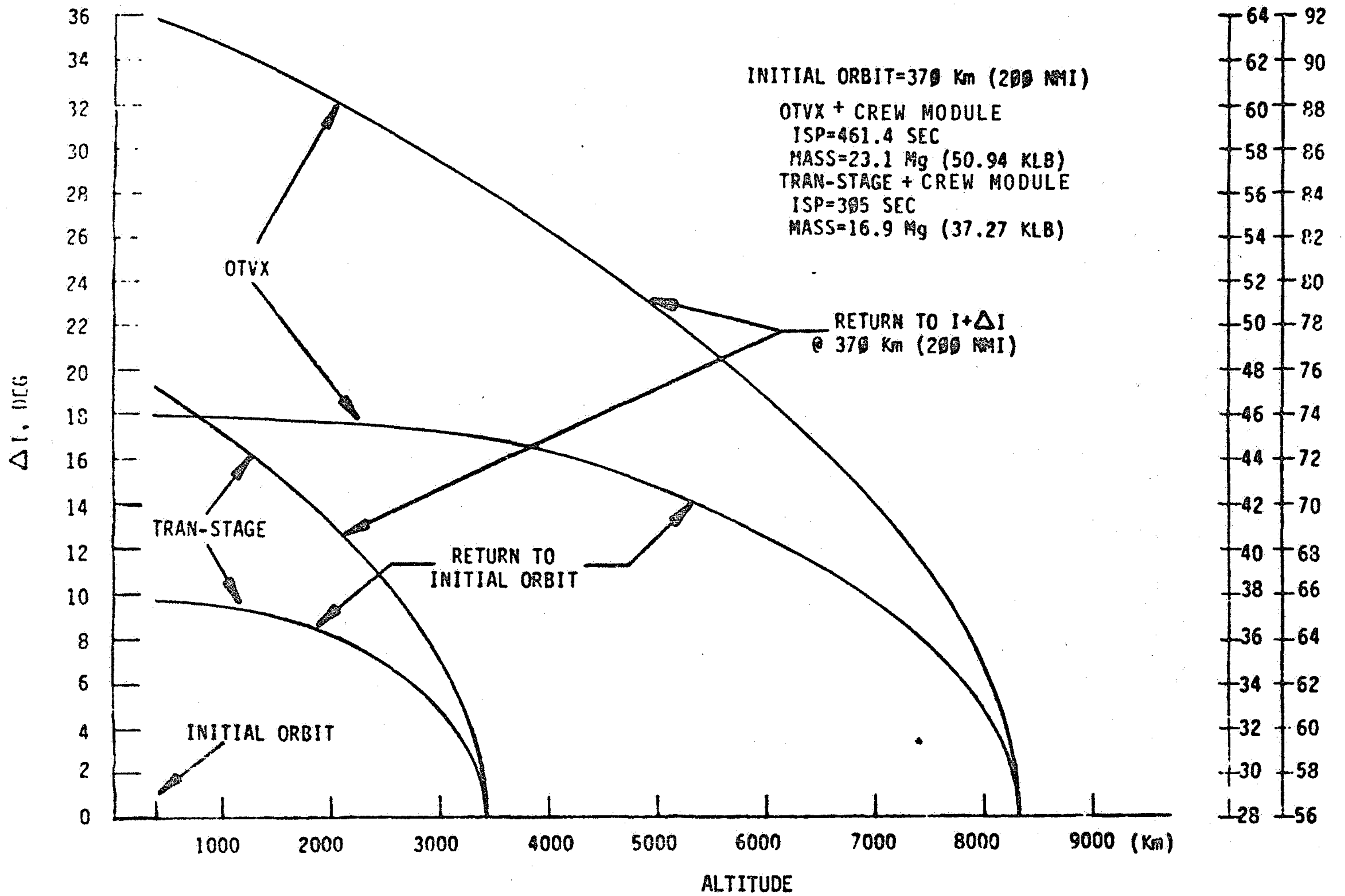


Figure 4. — Requirement for free volume per man as a function of mission duration.

	LENGTH, M(FT)	DIAMETER, M(FT)	WEIGHT, KG(LB)
CREW MODULE	4.35(14.3)	3(9.8)	7785(17,165)
PROPULSION MODULE			
OTVX	9.15(30)	4(13.1)	18,594(41,000)
TRANSTAGE	4.63(15.2)	3.05(10)	12,390(27,320)
MOSS			
OTVX	13.5(44.3)	-	26,379(58,165)
TRANSTAGE	9(29.5)	-	20,175(44,486)
SHUTTLE PAYLOAD LIMIT	18.3(60)	4.6(15)	18,594(41,000)*

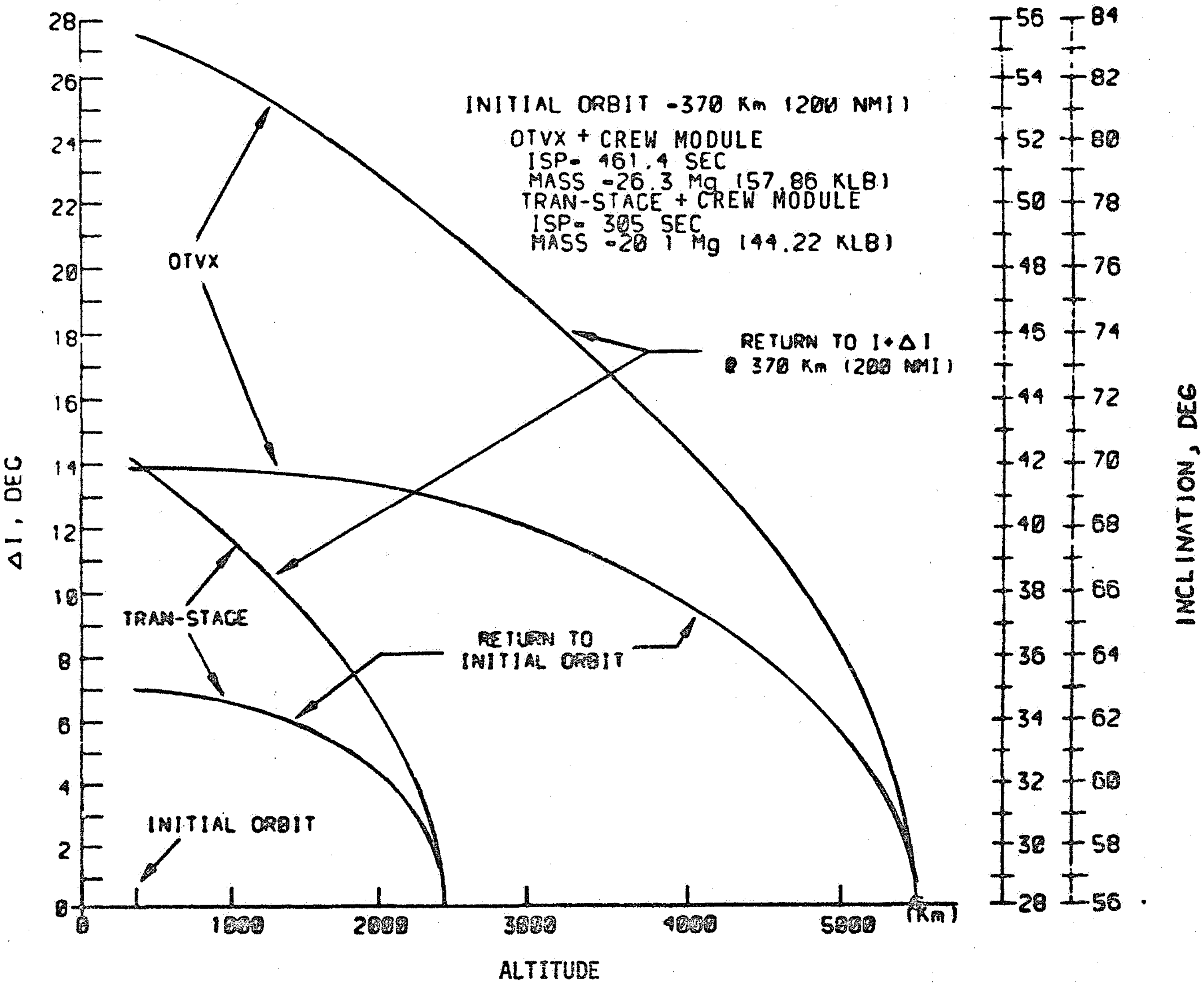
*370KM(200 N. MI) 56^{0} ORBIT

Figure 5. Comparison of MOSS physical characteristics and Shuttle payload limitations.



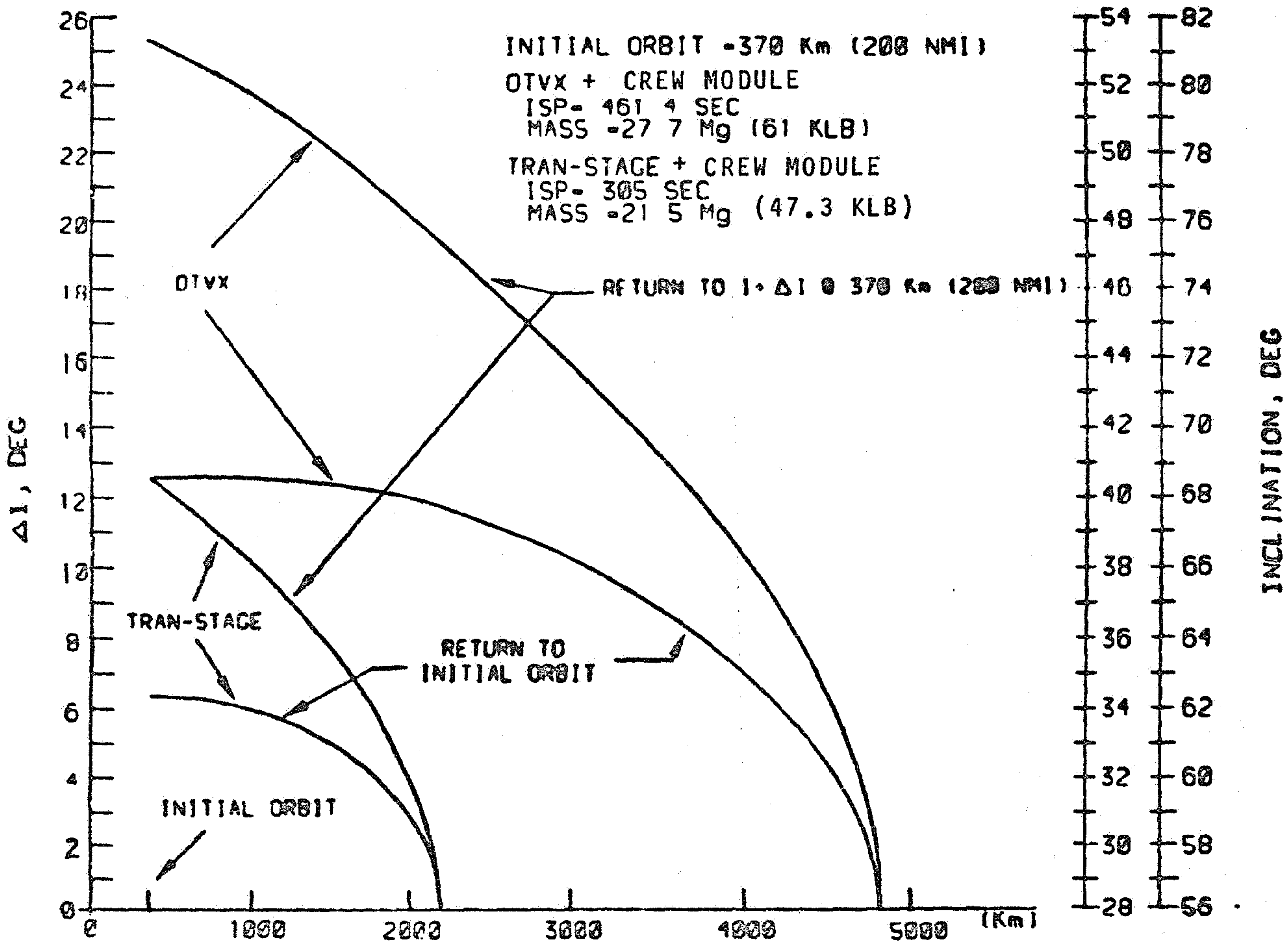
(a) Payload weight 4.54 Mg (10 Klb)

Figure 6. — Orbit altitude and inclination change envelope for MOSS with OTVX and transtage propulsion modules.



(b) Payload weight 7.71 Mg (17 klb)

Figure 6. — Continued.



(c) Payload weight 9.1 Mg (20 klb)

Figure 6. -Concluded.

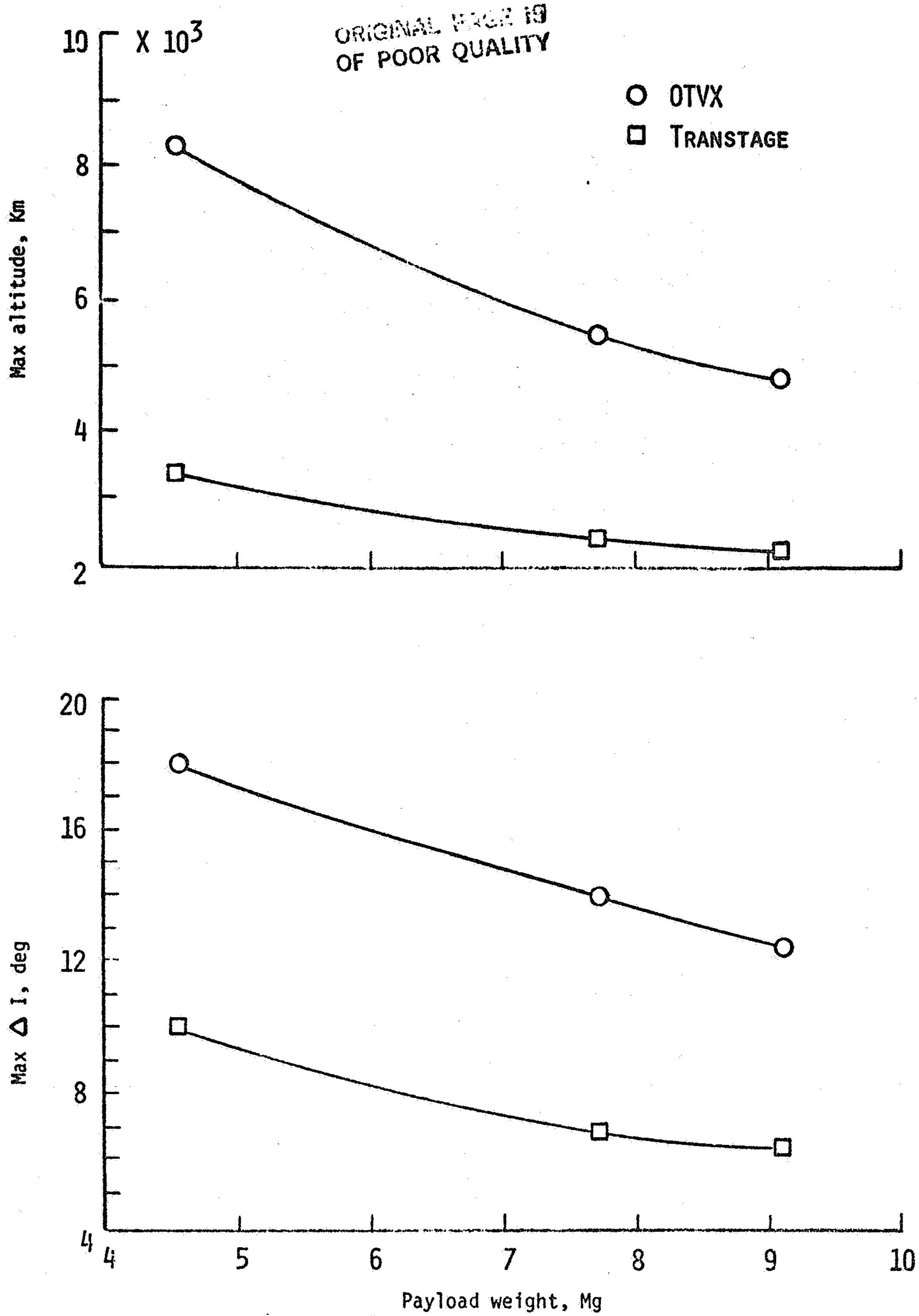


Figure 7. Effect of payload weight on performance assuming return to initial orbit.

	US		Friendly		USSR		Total	
Propulsion	R	I	R	I	R	I	R	I
OTVX	14	5	12	7	25	54	51	66
Transtage	6	4	9	2	3	2	18	8

R - Rendezvous

I - Intercept

Figure 8. - Number of satellites launched beginning January 1975 and still operational December 1980 that are accessible to MOSS.

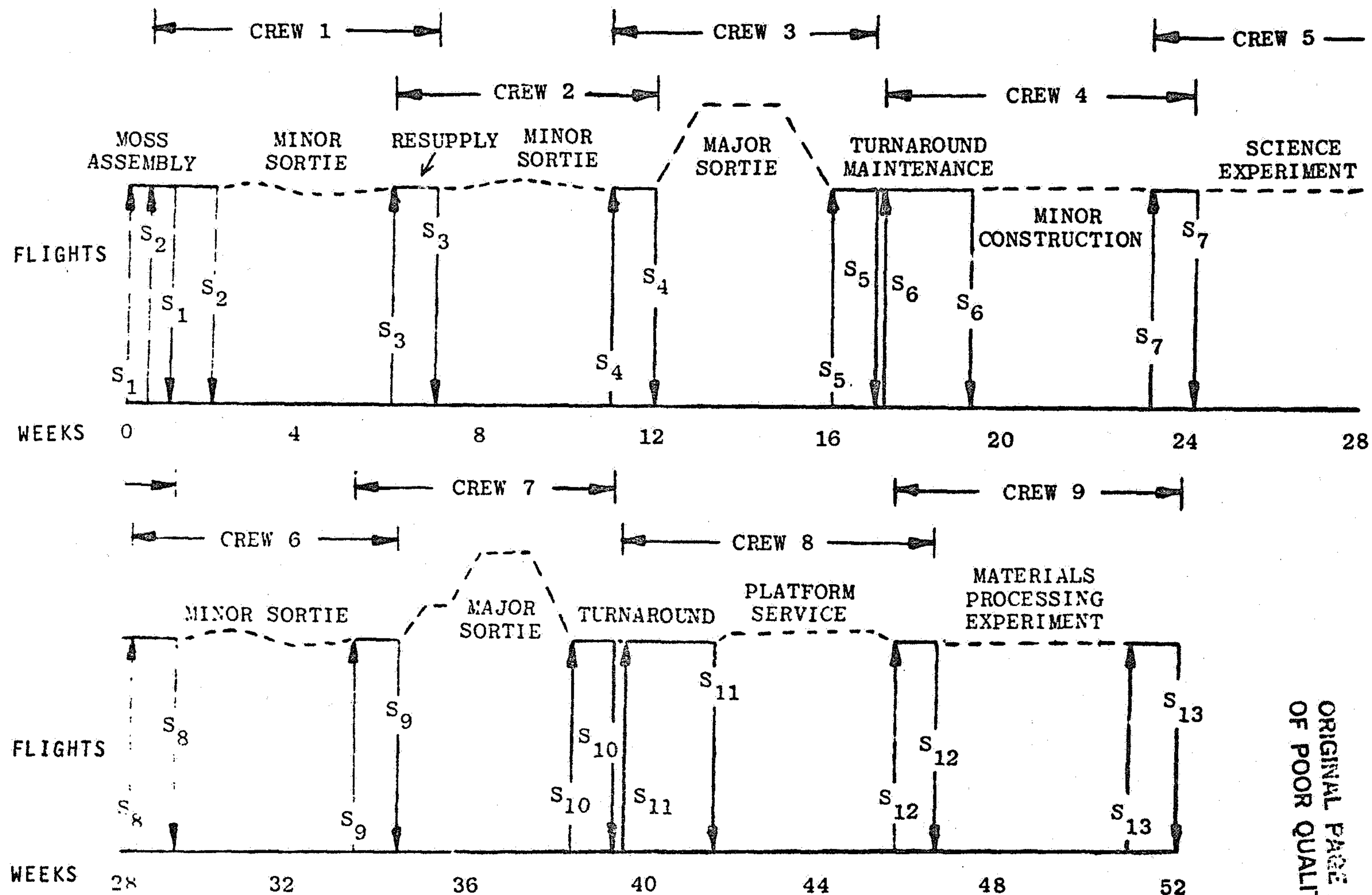


Figure 9. — One-Year MOSS Mission Model

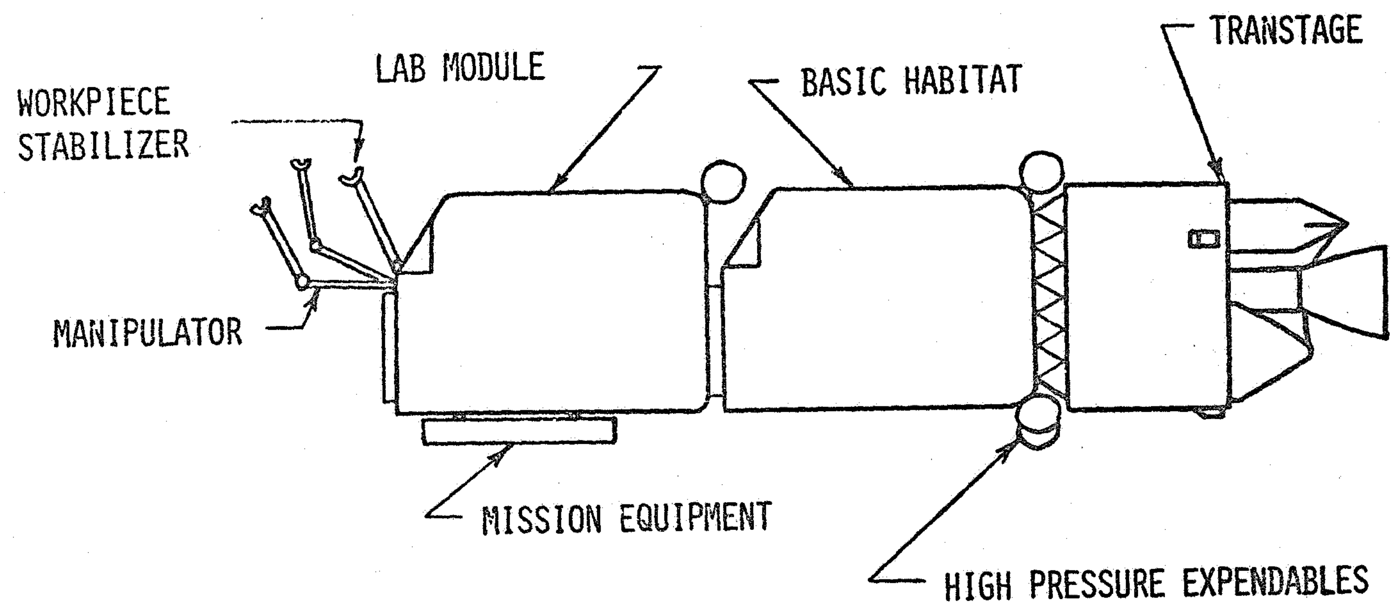


Figure 10. MOSS with two crew modules for expanded capability.

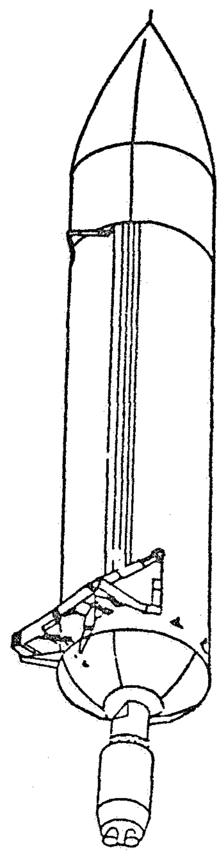


Figure 11 — MOSS-Shuttle External Tank Gravity Stabilized Concept.

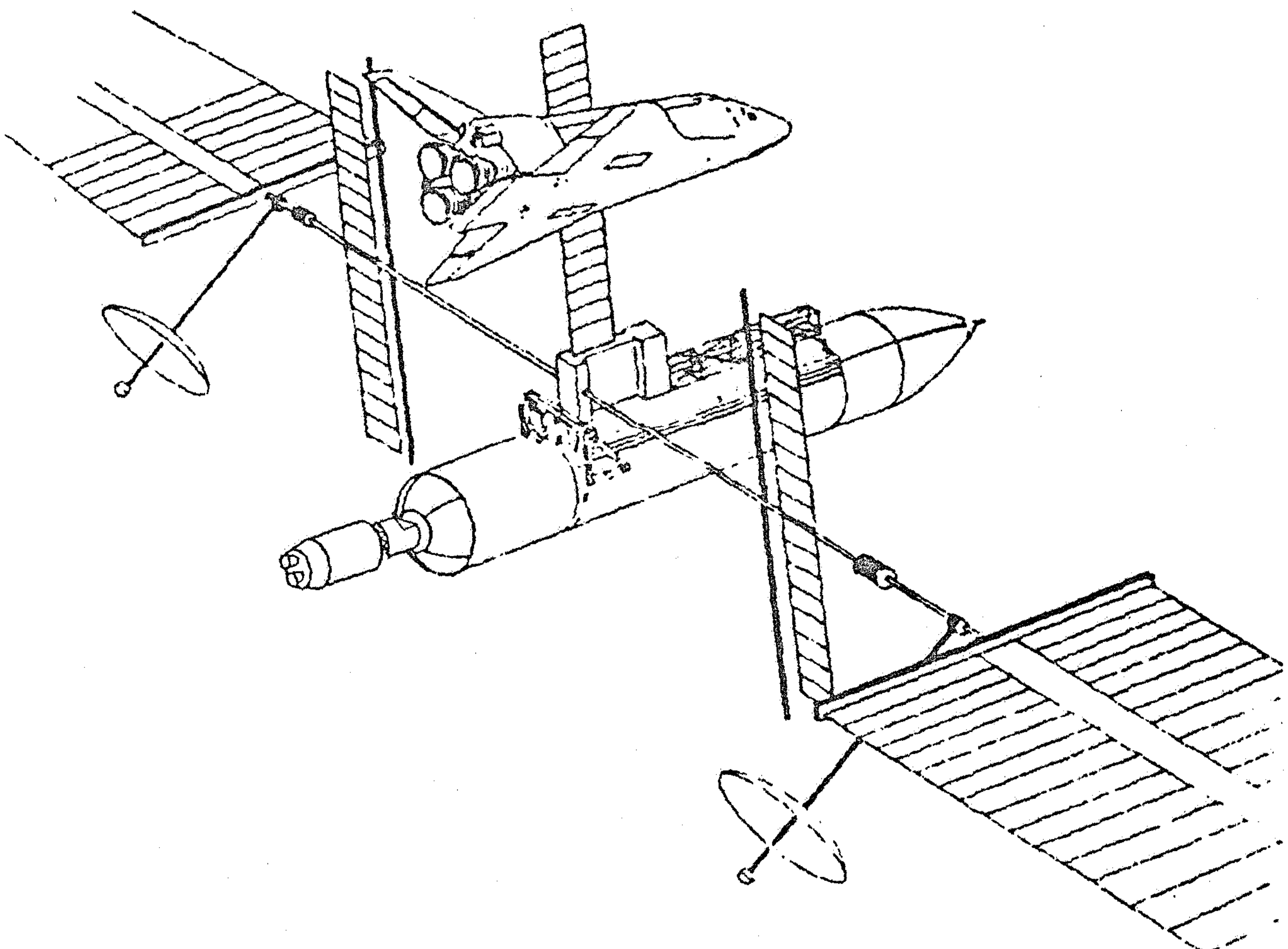


Figure 12. — MOSS-Shuttle External Tank space station concept.

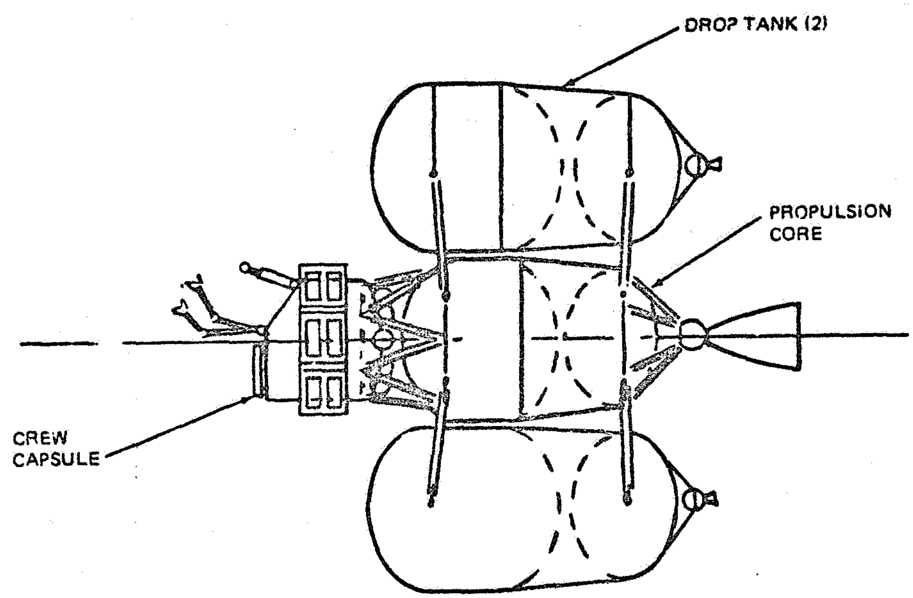


Figure 13. Grumman manned orbital transfer vehicle with two drop tanks.